Diamond-Like Nanocomposites to Mitigate Friction and Wear

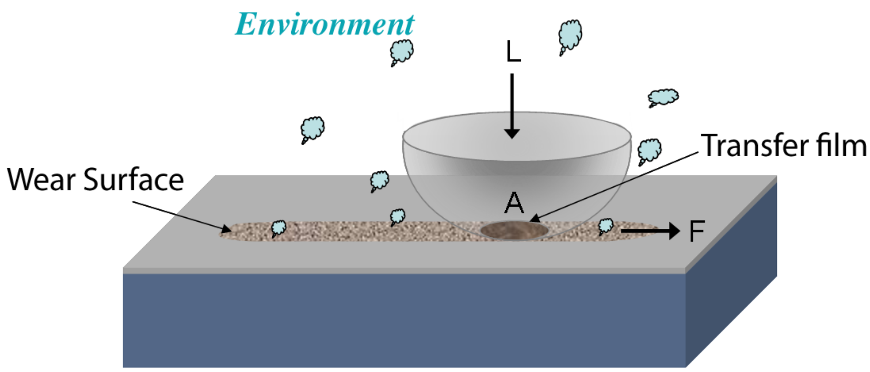

Figure 1: Schematic of a hemi-spherical pin sliding on a coated substrate. Tribology is a systems property, principally governed by tribochemical reactions and contact mechanics.

Many analytical techniques are needed to understand all aspects of friction and wear

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According to the classical theory of Bowden and Tabor, friction force F is a product of the area of contact A and the interfacial shear strength τ (see Figure 1). Thus, the coefficient of friction μ can be expressed by: $\mu = F/L = A\tau/AP = \tau/P$, where P is the contact stress and L is the load. In principle, a hard material with a soft skin ought to provide a low coefficient of friction μ by reducing the interfacial shear τ and increasing the contact stress P. Environment also plays a significant role in determining the tribological behavior of a material. Many tribological contacts result in transfer of material from one surface to the other, plus surface chemical reactions with the surrounding environment, resulting in wear surfaces whose chemistry is significantly different from the bulk.

In the search for an environmentally-robust lubricant between contacting surfaces, Sandia is investigating the fundamental mechanisms of friction in diamond-like carbons, specifically the role of "tribochemistry" on friction. Under consideration is a diamond-like nano-composite (DLN) coating, produced by Bekeart Advanced Coatings Technology, and processed from siloxane precursors by plasma-enhanced chemical vapor deposition. It has an amorphous structure consisting of two interpenetrating networks, a diamond-like (a-C:H) and a quartz-like (a-Si:O), with minimal bonding between the two networks. The DLN coating exhibits environmental robustness with a μ of 0.02 in dry nitrogen and ~0.2 in humid air, with minimal wear in both environments. In both cases, an extremely thin layer of the coating got transferred to the counterface ball during the initial run-in period. In a first-of-its-kind surface analytical study, researchers analyzed the transferred films on the counterface balls by Time-of-Flight Secondary Ion Mass Spectroscopy (ToF-SIMS), and constructed the color montages of SIMS maps (Figure 2) using Sandia's Automated eXpert Spectral Image (AXSIA) software. They believe that by forming transfer films of long range carbon and hydrogenated carbon in dry nitrogen (Figure 2b), and predominantly silicon oxide species in humid air (Figure 2a), DLN is able to adapt itself to both dry and humid environments.

Sandia is also applying focused ion beam microscopy (FIB) and finite element analysis modeling (FEM) to study coating-substrate interface reliability. FIB sections of wear scars are routinely made to visualize friction-induced subsurface deformation and to validate FEM. In all cases where the contact stress induces plastic deformation in the underlying substrate (see the focused ion beam cross-section of the wear scar on the left in Figure 3), fracture and de-lamination of the coating results. This underscores the need to design the coating architecture (e.g., a hard coating sandwiched between DLN and the softer substrate) to withstand higher operating stresses.

Besides the environmental robustness, there are engineering issues such as coverage on sidewalls, and masking certain areas of a small part to enable subsequent welding and joining operations (Figure 4) that must be addressed. Sandia is currently working on the application of DLN coatings for advanced surety mechanisms to enable designers more flexibility in the choice of the operating environment.

References

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2. J. M. Jungk, J. R. Michael and S. V. Prasad, *Acta Materialia*, **56** (2008) 1956-1966.

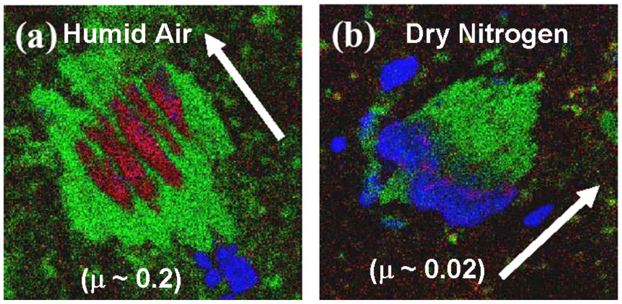

Figure 2: Time-of-flight SIMS (negative secondary ion image) maps of silicon oxide (red), long range carbon (green), and hydrogenated carbon (blue) fragments on the counterfaces generated in (a) humid air and (b) dry nitrogen. The arrow indicates the sliding direction. The image size is 100 x 100 mm^2. Sandia's AXSIA software was used to generate the montage of SIMS image maps.

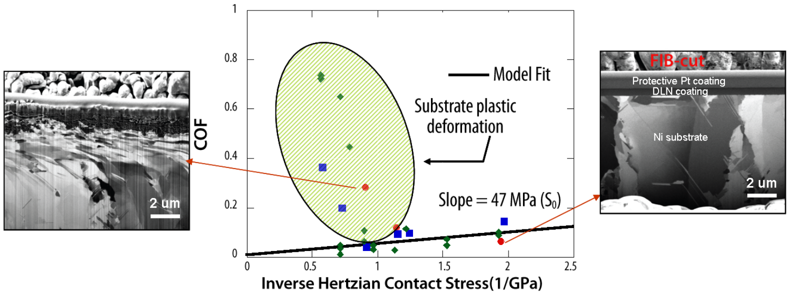

Figure 3: The coefficient of friction (COF)decreases with increasing contact stress, in agreement with the classical theory (straight line). The shaded region corresponds to the case where the contact stress induces plastic deformation in the underlying substrate (see the focused ion beam cross-section of the wear scar on the left), causing fracture and de-lamination.

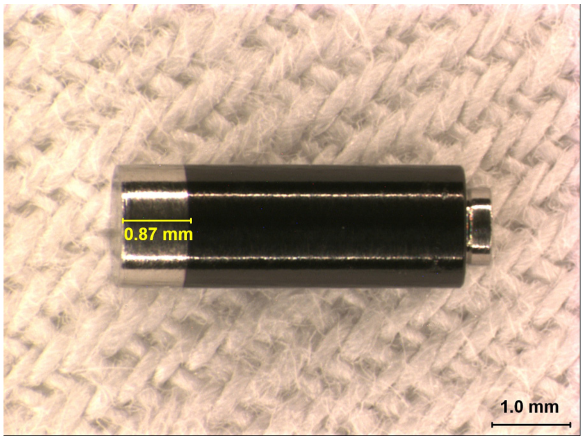

Figure 4: Application of diamond-like nanocomposite coatings for Advanced Surety Mechanism components. One end of the pin was masked to enable subsequent welding and joining operations.

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